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DIGITAL LINE STORE STANDARDS CONVERSION:
determination of the optimum interpolation aperture function

G.M. Le Couteur, B.Sc.

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION October 1973

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Summary

The work described in this report consisted mainly of a series of subjective tests with the aim of exploiting the extreme flexibility which can be built into digital line-store converters. This report presents the experimental results which follow from the mainly theoretical work described earlier in the companion Research Department Report No. 1972/28. Prior reading of that report is advised.

The work described herein concludes that satisfactory performance is obtained using an interpolation aperture function formed from four ordinates, and that this function is adequately described in a digital system by 36 coefficients each represented in magnitude by a four-bit binary number together with one extra bit for coefficient polarity.

Issued under the authority of

P. Rainger

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

(PH-110)

DIGITAL LINE STORE STANDARDS CONVERSION: DETERMINATION OF THE OPTIMUM INTERPOLATION APERTURE FUNCTION

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1. Introduction

The object of the work described in this report was to build the experimental equipment necessary to make a thorough investigation into the choice of interpolation parameters for use by Designs Department in their design of a prototype digital line-store standards converter for the Television Service.

A number of factors were considered, related to the prospective performance, cost, reliability, and complexity of the final equipment required.

A photograph of the experimental apparatus is shown in Fig. 1; it was designed with flexibility in mind, thus making it possible to look at the performance of a wide range of different interpolation aperture functions having widths of up to eight ordinates. This means that interpolation could be carried out using contributions from eight successive lines of a television field simultaneously, if required. The experimental work involved subjective tests which were aimed at determining the cheapest and least complex aperture functions which would achieve subjectively satisfactory results.

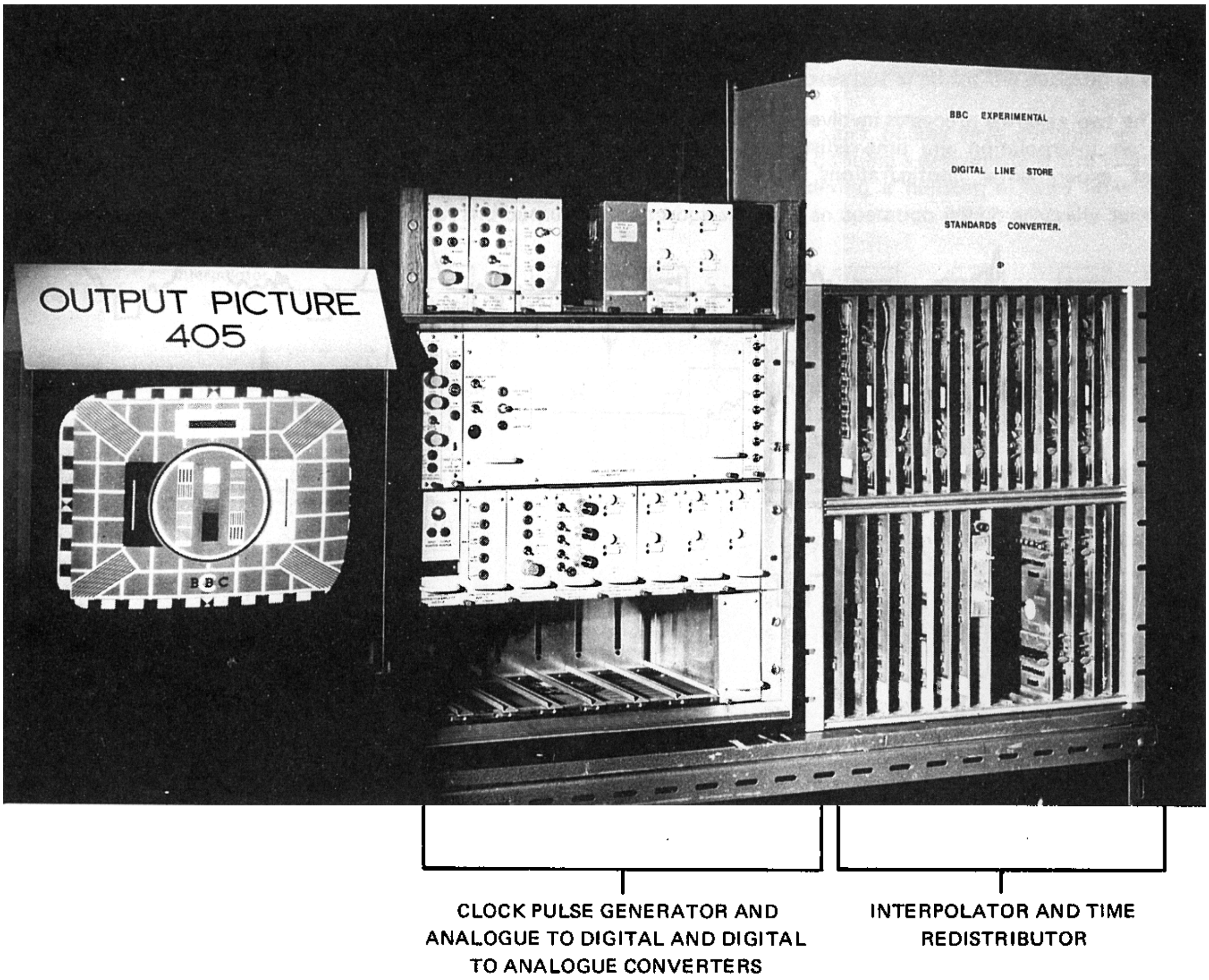
OUTPUT PICTURE 405
BBC
BBC EXPERIMENTAL DIGITAL LINE STORE STANDARDS CONVERTER.
CLOCK PULSE GENERATOR AND ANALOGUE TO DIGITAL AND DIGITAL TO ANALOGUE CONVERTERS
INTERPOLATOR AND TIME REDISTRIBUTOR

Fig. 1 - Photograph of complete experimental equipment

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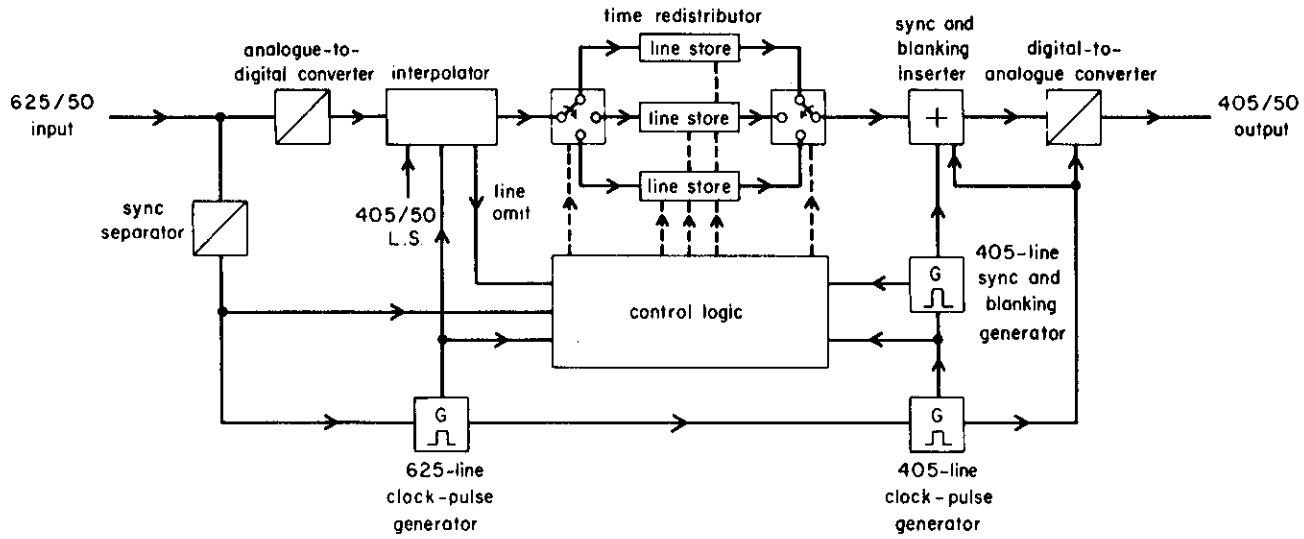

time redistributor
line store
line store
line store
analogue-to-digital converter
interpolator
sync and blanking inserter
digital-to-analogue converter
625/50 input
405/50 output
sync separator
405/50 L.S.
line omit
control logic
G
405-line sync and blanking generator
G
625-line clock-pulse generator
G
405-line clock-pulse generator

Fig. 2 - Block diagram of the experimental digital line store converter

2. Description of apparatus

The layout of the converter in block schematic form may be seen in Figs. 2 and 4. Fig. 2 shows the whole converter, and Fig. 4, which is described later, shows the interpolator in greater detail.

The two essential processes involved in standards conversion are interpolation and time-redistribution, and two different experimental configurations were considered. First, the arrangement which was chosen and is illustrated in Fig. 2, where interpolation takes place before time-redistribution, and second, a system in which interpolation and time-redistribution take place together, and share the same line stores. This latter method has the advantage that economy is possible in the total number of line stores that would have to be used in the converter, and it is being considered as a method which might be used in a practical standards converter. However, the system illustrated in Fig. 2 was most suited to an experimental investigation of

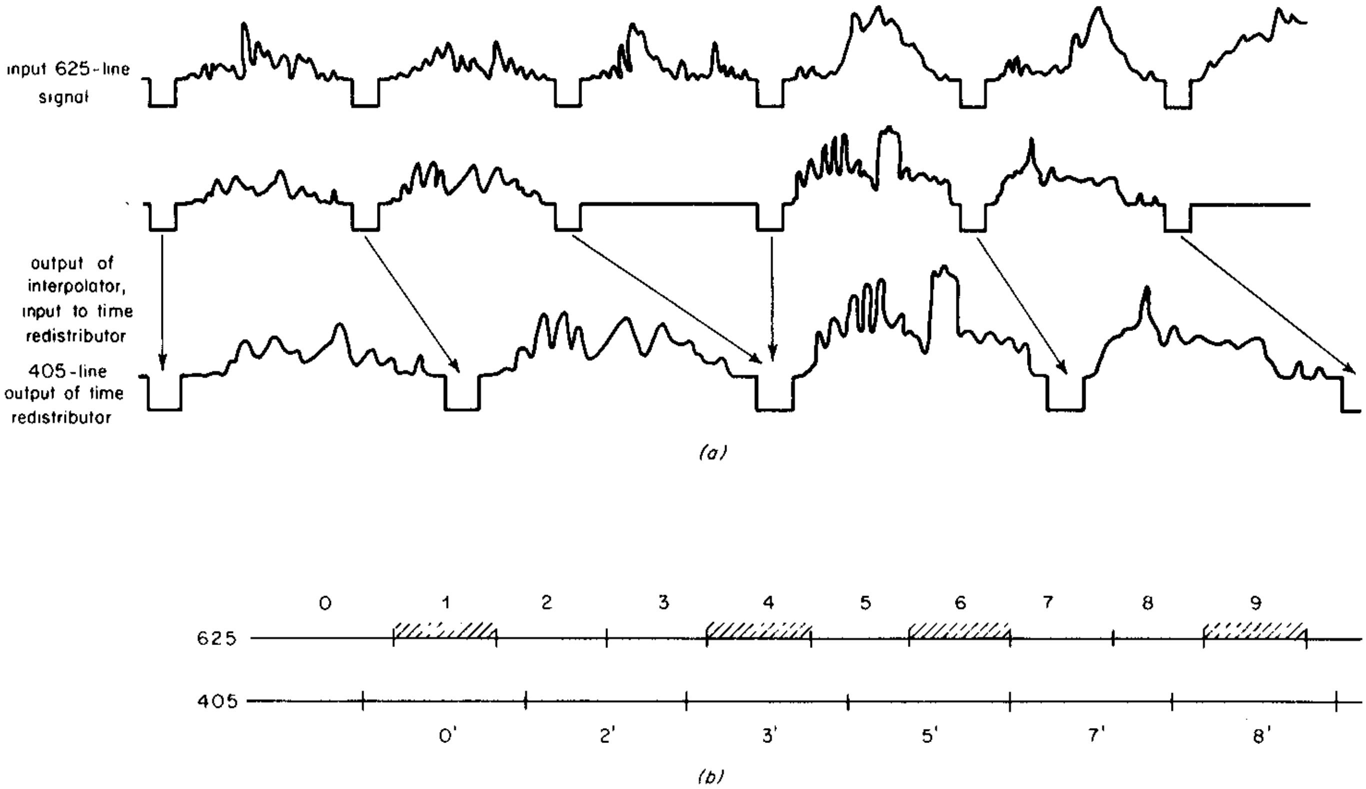

input 625-line signal
output of interpolator, input to time redistributor
405-line output of time redistributor
(a)
0
1
2
3
4
5
6
7
8
9
625
405
0'
2'
3'
5'
7'
8'
(b)

Fig. 3

(*a*) Appearance of signals at three points in the converter (*b*) Typical phase relationship between input and output line synchronising pulses interpolation, since it lent itself to great flexibility and enabled the parameters associated with interpolation to be varied. Moreover, at the time of the investigation, the time-redistributor together with its control circuitry had already been designed and built as a part of a previous project.[2] It was therefore possible to channel all the available effort into the design and construction of the experimental interpolator.

The signal processing carried out by the time-redistributor is illustrated in Fig. 3(*a*). Its function is to 'stretch' and re-time the irregular groups of lines emerging from the interpolator in such a way as to produce a continuous sequence of lines, each of the correct duration. This is achieved by reading the information into each line store (Fig. 2) in sequence, and holding it until it is required. It is then read out at an appropriate slower clocking rate. The interpolator produces picture information, derived from the incoming signals, having line and field durations identical with the input signals. However, since it has to produce 405 output lines for every 625 input lines, after roughly every third input line there is a gap of one line at the interpolator output. This can be understood more completely with the aid of Fig. 3(*b*) which shows a typical phase relationship between input and output line-synchronising pulses. The line positions which are shown shaded are those for which the interpolator would not produce any output. The criterion which determines the positions of these blank lines is as follows. If no output line-synchronising pulses appears during an input line period, then the interpolator produces no information during that time; this corresponds to the situation in which no output line is located between two input lines (when the input and output rasters are imagined to be superimposed on top of one another).

The block diagram of the interpolator is shown in Fig. 4. There are seven one-line delays connected in series, with signal tapping points between the delays; thus the signals from eight successive lines are available simultaneously. These signals then pass into multipliers where they are weighted by pre-determined, stored coefficients, having either positive or negative polarity, generated by the interpolation coefficient generator. These coefficients can be defined in magnitude by up to seven bits, plus one extra bit which defines the polarity of the coefficient. The multiplied signals can appear at one of two alternative outputs of the multipliers, depending on the polarity of the coefficients. After multiplication, all the signals of like polarity are added in 14 separate adding units, and the total negative part is subtracted from the total positive part. This forms the output signal from the interpolator.

The coefficient generator consists of two pre-programmed, plug-in coefficient store boards A and B, which are selected by the switch S, together with the interpolation coefficient selector which compares the relative timings of the 625- and 405-line synchronising pulses (as illustrated in Fig. 3(*b*)). This unit either selects the coefficients for routing into the multipliers, or decides that the interpolator should produce no output at all for the duration of one line.

The plug-in store boards were designed so that the coefficient values defining a desirable aperture function can be preset by soldering a number of wire links between appropriate pins, an operation which generally takes about

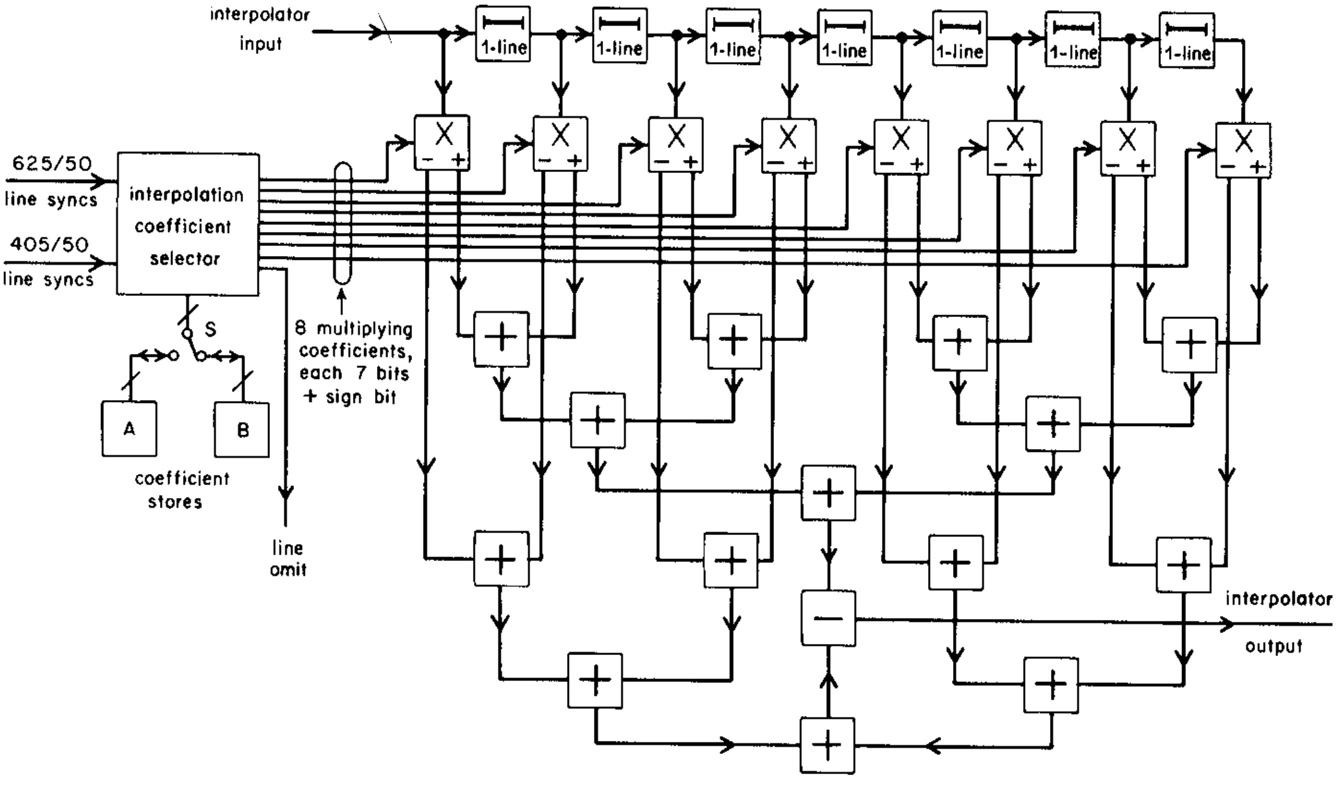


Fig. 4 - Block diagram of the experimental interpolator

five man-hours per board. In order to be able to set up a desired aperture function quickly, a special plug-in board was constructed in which the wire links were replaced by a bank of switches. These 296 switches could be set up in roughly five minutes from switch-position data, produced by the computer, for each aperture function. Only when an aperture function was considered suitable for inclusion in subjective tests was it transferred on to one of the semi-permanent coefficient boards.

3. Quantisation of the aperture function

From the ratio of 625 to 405, it is evident that there are 81 discrete positions which an output '405' line can occupy with respect to two successive input '625' lines. Hence, in order to exploit to maximum advantage the properties of a given interpolation aperture having n ordinates, (i.e. using signals from n lines) the number of coefficients required to be stored would be 81 n. It follows, then, that an eight-ordinate aperture would require the storage of 648 coefficients. In practice this could be reduced to 324 coefficients, since a reasonable constraint on the shape of the aperture function is that it should be symmetrical. Thus, under these circumstances, only half the total number of coefficients needs to be stored.

For practical purposes it seemed unnecessary and undesirable to store all the coefficients, and an approximation was made in which it was assumed that the 81 positions could be sufficiently well approximated by providing coefficients appropriate to only nine positions of an output line relative to two input lines. Fig. 5 illustrates how a typical eight-ordinate aperture appears when quantised to this degree of resolution along its abscissa. It is known that this approximation will give rise to unwanted spurious effects in the picture, but a theoretical analysis of the problem, which may be found in the preceding report (1972/28), suggested that the level of unwanted components would be acceptably low. This was borne out by experiment.

Because the signals being handled were in a digital form, the stored aperture function, in addition to being quantised as illustrated in Fig. 5, was also, by its nature, magnitude quantised. The shape of an aperture of a given width is defined by the values of the multiplying coefficients applied to each ordinate. Hence the coarseness of quantitation of the coefficients determines the coarseness of magnitude quantitation of the aperture function. It was felt that the coarseness of magnitude quantisation required for the interpolation aperture was a parameter well worth investigating, because of the possibility of economising in the number of bits needed to define the interpolating coefficients. It should be emphasised that this does not imply a reduction in the number of bits defining the output signal of the converter. The subjective tests indeed confirmed that a useful degree of economy was possible in this way. These tests are more fully described in Section 6.2.

4. Computer optimisation of aperture functions

It has been shown elsewhere[1] that a theoretically optimum interpolation aperture is one having a vertical spectrum with a sharp cut-off at half the input sampling frequency, $f_i/2$ where f_i is the input sampling frequency in cycles/picture height (defined as the number of active lines in one field of the input 625-line television waveform). This ideal spectrum is represented in Fig. 6(*a*) and the aperture giving rise to it, which is its Fourier Transform is shown in Fig. 6(*b*). This function can be expressed as:—

$$F(d) = \frac{\sin \pi f_i d}{\pi f_i d}$$

where d is the distance in terms of picture height. Practical apertures, unlike the sin x/x functions, are limited to finite widths and correspondingly, their vertical spectra suffer departures from the ideal. In order to discover the optimum spectrum shapes available with apertures of limited width W, a computer program was run in which it was assumed that the aperture function could be expressed as a limited Fourier series of the form:

$$F\left(\frac{d}{W}\right) = A_0 + A_1 \cos\frac{2\pi d}{W} + A_2 \cos 2\frac{2\pi d}{W} + \ldots A_n \cos n\frac{2\pi d}{W}$$

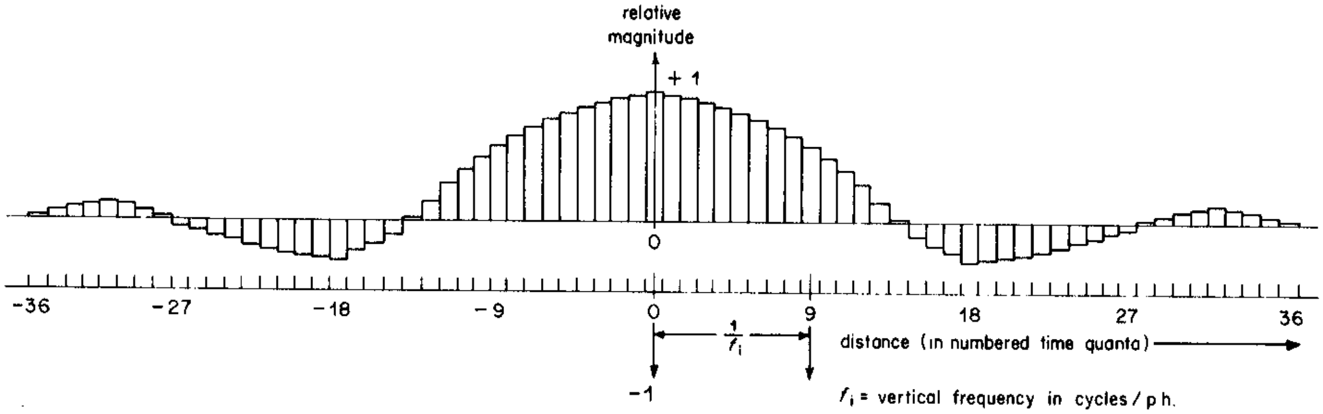


Fig. 5 - 8 ordinate aperture, time quantised to the degree of resolution used in the converter

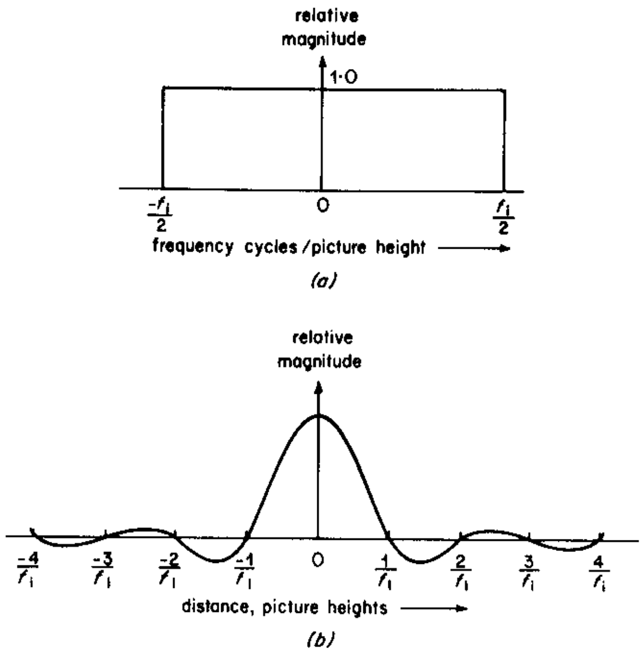


Fig. 6

(*a*) Ideal spectrum cutting off at $f_i/2$

(*b*) Aperture function of sin x/x form, having the spectrum illustrated above

It can be shown that the values of the corresponding spectrum at frequencies spaced at multiples of $1/W$ cycles/p.h. are A_0, A_1, A_2, A_3, . . . A_n, and these values are all that is necessary to completely define the spectral function. The values of the spectrum at all other points is obtained by interpolation using scaled sin x/x functions centred on each of these points, and having zeros at $1/W$ cycles/p.h. apart.

The computer program required the reading-in of values A_0, A_1 . . . etc., (the number of terms depending on the width of the aperture), and a plot was produced of both the spectrum and the resulting aperture function. Computer optimisation techniques were at first devised by which the values of A were varied so as to optimise the shape of the spectrum according to certain constraints; however these were discarded in favour of a more direct approach in which the optimum values of A were finally decided by a method of successive approximation which worked in the following way. The operator initially chose a set of values for A falling on what he intuitively considered to be the best approximation to the ideal spectrum corresponding to a certain aperture width. The computer then printed out the corresponding spectrum curve passing through these points by summing sin x/x functions as previously explained. It was found that if the choice in the values of A was too ambitious, i.e. such as to impose too fast a roll-off around the desired cut-off frequency, the spectral values between the fixed points varied rapidly, resulting in overshoots of the curve. One of these curves with excessive overshoots is reproduced in Fig. 7 to illustrate the effect. On the basis of the shape of the curve obtained, a modified set of values of A was chosen and fed again into the computer, and the process was repeated until it was evident that the optimum has been reached. The aim was to minimise the values above the chosen cut-off frequency, whilst retaining a reasonably flat curve in the desired band with the maximum possible rate of cut-off. Fig. 8 illustrates the optimum spectra obtained for aperture widths from 2 to 8 ordinates. Theoretically, it seemed reasonable to set the cut-off frequency at $f_i/2$, and in practice it was found that apertures which had a lower cut-off frequency gave rise to a noticeable deterioration in vertical definition, whilst those with a cut-off greater than $f_i/2$ suffered interpolation errors because of the appearance of unwanted components in the passband. For each aperture width it was therefore possible in a fairly short period to establish the optimum parameters for the aperture function. The aperture functions for the examples illustrated in Fig. 8 are plotted in Fig. 9. It will be appreciated that since the apertures are all symmetrical, it is only necessary to show the positive distance axis. In general, it

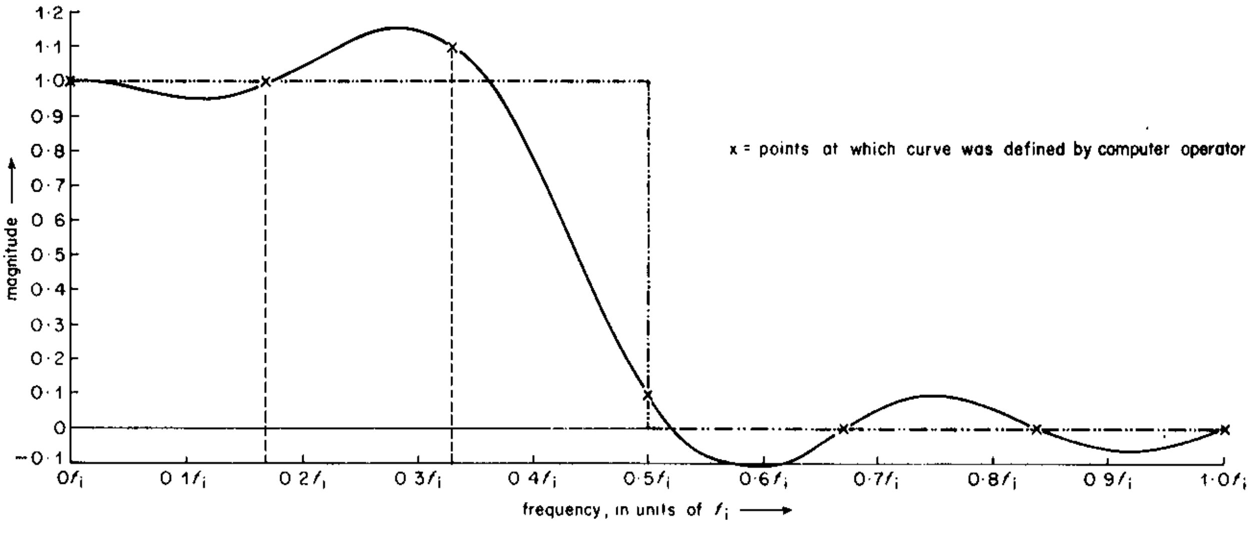


Fig. 7 - Spectral plot for 6 ordinates, illustrating large overshoots resulting from an attempt to achieve an excessively rapid cut-off

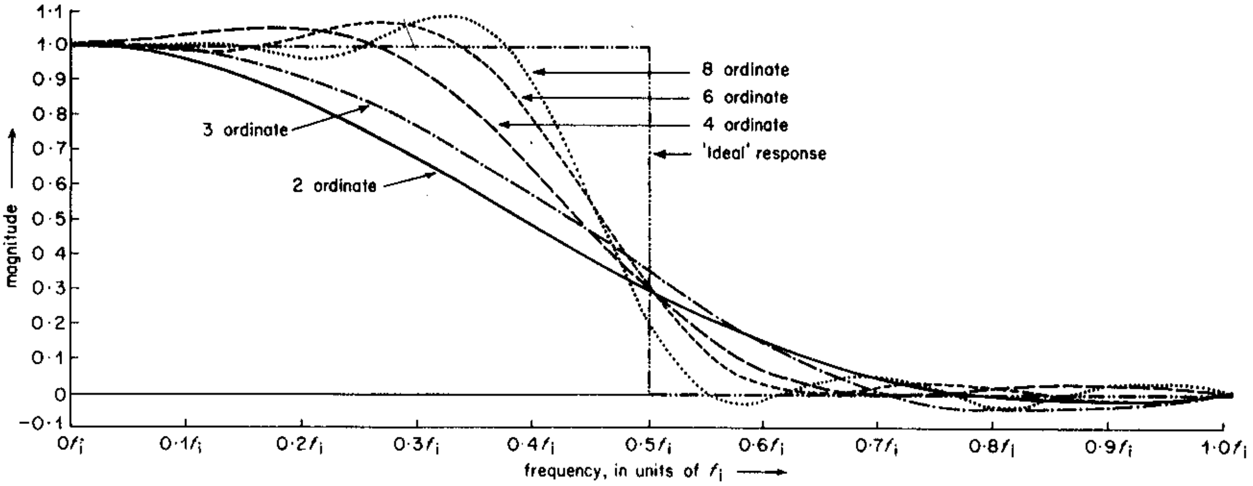


Fig. 8 - Plot of spectra obtained for aperture widths ranging from 2 to 8 ordinates

was found that the optimum spectra usually gave rise to apertures having non-zero end values.

Some indication of the relative performances of some of the apertures used in the subjective tests may be obtained by inspecting the sloping edges in the photographs in Fig. 10. This shows the bottom right-hand quadrant of Test Card C as it is reproduced by the following apertures.

(a) Zero Order
(b) 2-Ordinate linear
(c) 2-Ordinate optimised
(d) 4-Ordinate optimised

Coefficients defined by 7 bits

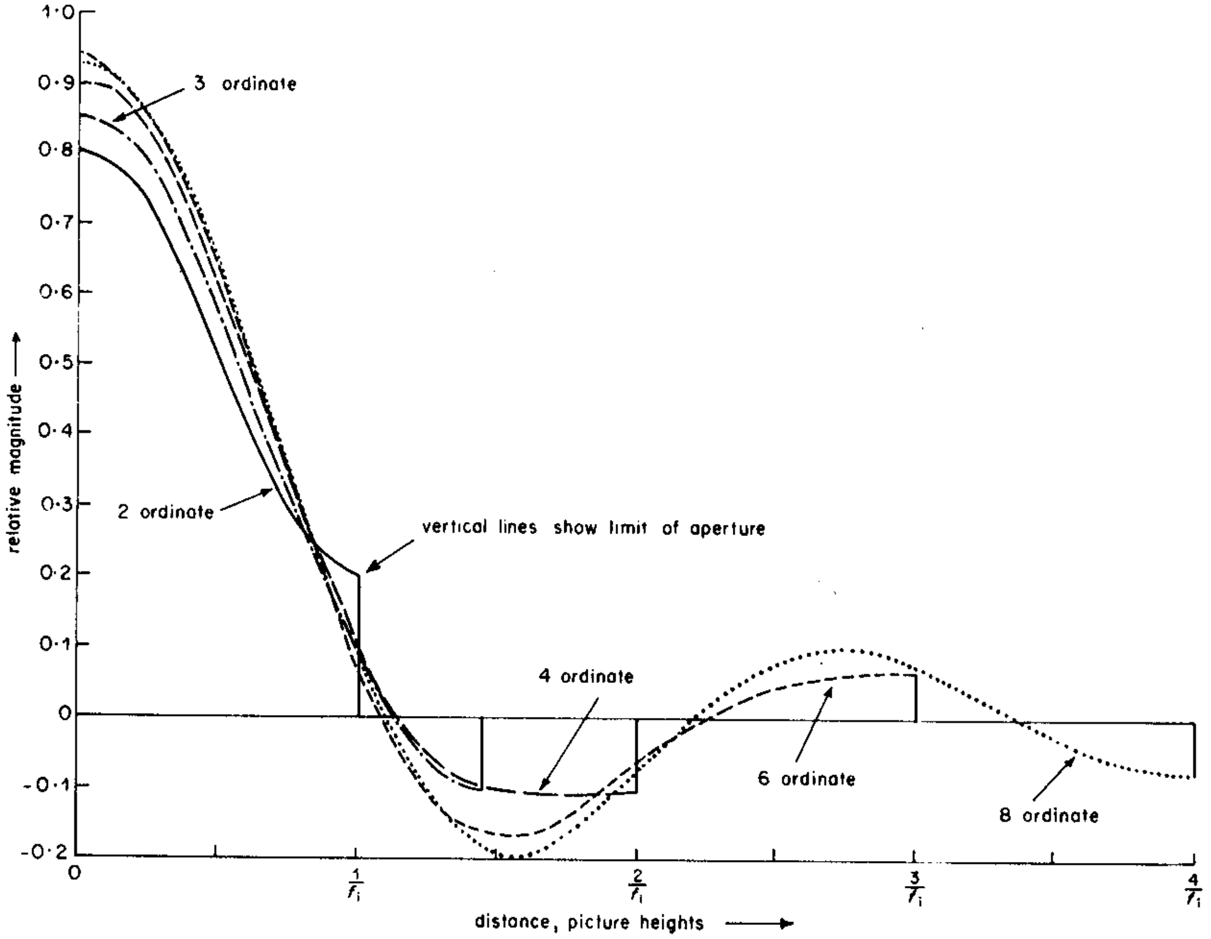
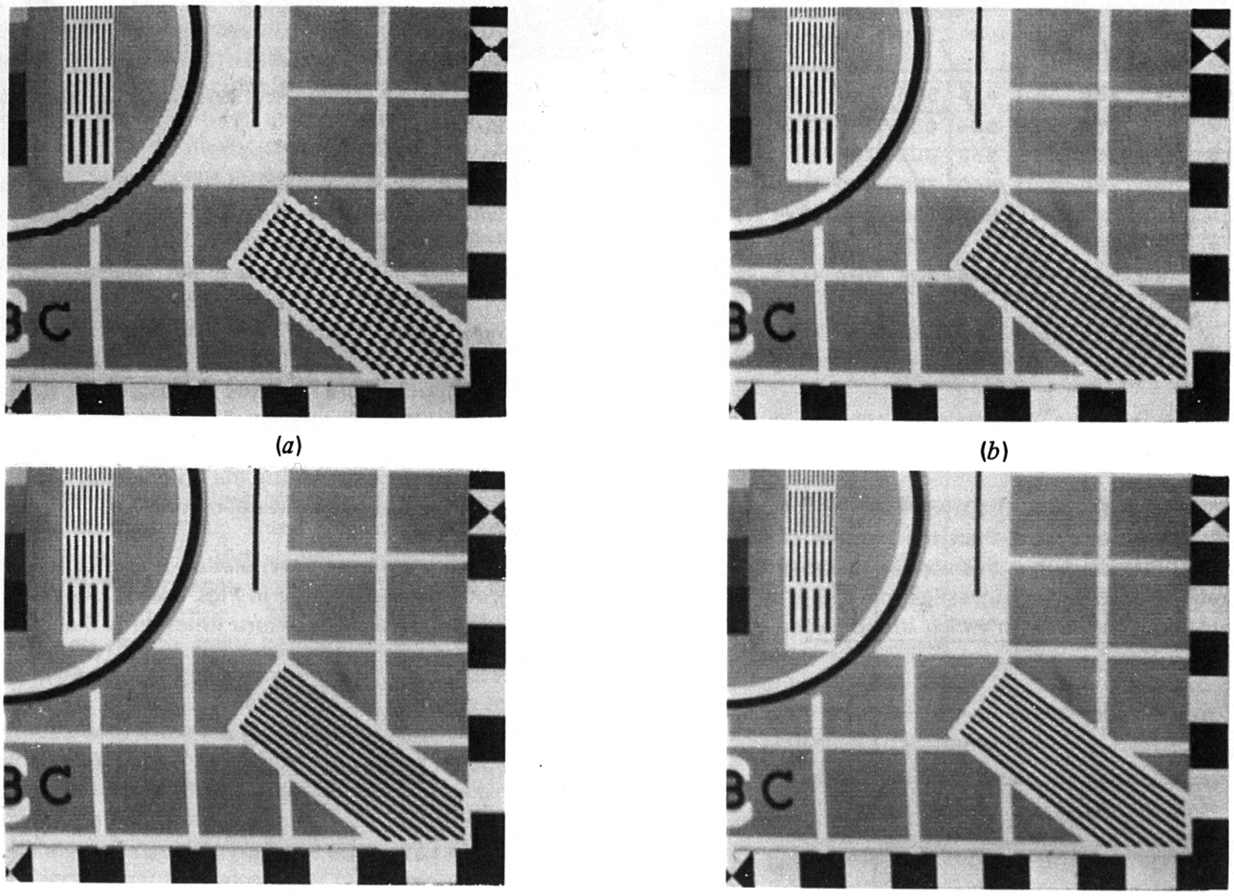


Fig. 9 - Aperture functions for the spectra illustrated in Fig. 8



(*a*) (*b*)

(*c*) (*d*)

Fig. 10 - Photographs showing the performance of
(*a*) Zero order interpolation (*b*) 2-ordinate linear interpolation (*c*) 2-ordinate optimised (*d*) 4-ordinate optimised

However, these photographs, as an indication of performance, should be treated with caution, since interpolation errors are sometimes visible as 25 Hz flickering components which, of course, cannot be reproduced here. Also, all interpolation errors become subjectively much more objectionable if the scene is moving. Thus the interpolation beat patterns (only just visible in the photograph) obtained with the two-ordinate optimised aperture were easily seen when the picture moved. Nevertheless, the photographs do show the relative improvement in performance as the spectrum of the aperture function approximates more closely to the ideal.

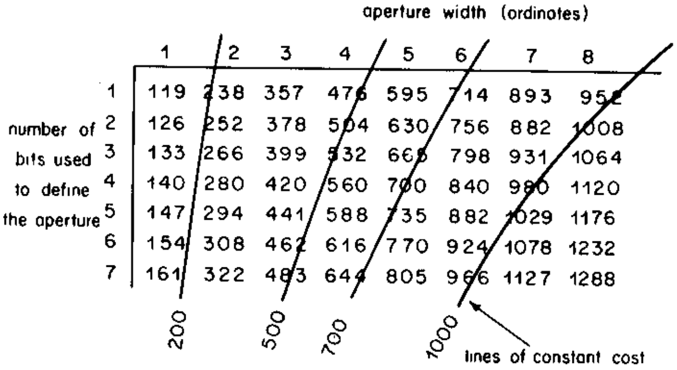
5. Outline of subjective tests

The interpolator in the experimental converter was designed to have a potentially better performance than any interpolator likely to be used operationally, so that subjective tests could go beyond the point where acceptable results could be obtained at minimum cost.

The subjective tests were divided into two groups, The first group was designed to evaluate the effect of varying the shape of the aperture function and, in particular, the tests sought to discover the minimum acceptable aperture-width. The second group of subjective tests was designed to discover how coarsely it was possible to quantise the multiplying coefficients.

The total number of coefficients to be stored was less amenable to variation for instrumental reasons, and the subjective tests were carried out using the maximum spatial resolution possible with the equipment, i.e. 9/81 of the ideal, a resolution which, from theoretical considerations, was considered to be adequate. This was borne out by the subsequent experimental investigations in which no evidence was found to suggest that this was giving rise to troublesome interference effects.

It was thought relevant to the subjective investigation to investigate how the cost of the interpolator was related to the number of bits in the multiplying coefficients, and to the width of the aperture. It might, for example, have been possible to trade the one for the other at some cost advantage, whilst maintaining the same performance. In fact, no evidence was found to support this supposition. It is nevertheless interesting to compare the relative importance of the two parameters to the cost of the machine. This is summarised in Fig. 11 which shows approximately cost-proportional coefficients derived as a function of the width of the aperture, in input-line ordinates, and the number of bits describing the interpolation coefficients. Also some contours of constant cost are plotted and these illustrate


aperture width (ordinates)
number of bits used to define the aperture
200
500
700
1000
lines of constant cost

	1	2	3	4	5	6	7	8
1	119	238	357	476	595	714	893	952
2	126	252	378	504	630	756	882	1008
3	133	266	399	532	665	798	931	1064
4	140	280	420	560	700	840	980	1120
5	147	294	441	588	735	882	1029	1176
6	154	308	462	616	770	924	1078	1232
7	161	322	483	644	805	966	1127	1288

Fig. 11 - Dependence of converter cost on number of ordinates and number of bits

that the width of the aperture always accounts for more of the total interpolator cost than the number of bits. It should be pointed out that this applies to the interpolator configurations used in this investigation and is not necessarily true for a converter in which interpolation and time-redistribution take place together.

6. Description of subjective tests and discussion of results

Throughout all the subjective tests, zero-order interpolation was included as well as two-ordinate linear interpolation. Zero-order interpolation uses only one line of information and corresponds to a flat aperture-function cutting off at $\pm 1/(2f_i)$ picture heights (see Fig. 12). It is often referred to as 'nearest line' interpolation, since the result may be regarded as being equivalent to forming each line of the output picture from the nearest line of the input picture, without modification. The performance of this aperture, as seen in Fig. 10(*a*) is highly unsatisfactory, but it served the purpose of reminding the observers of the nature of the impairments that they were looking for.

Two-ordinate linear interpolation does not belong to the family of curves illustrated in Figs. 8 and 9, but was also included in the tests; its aperture function is illustrated in

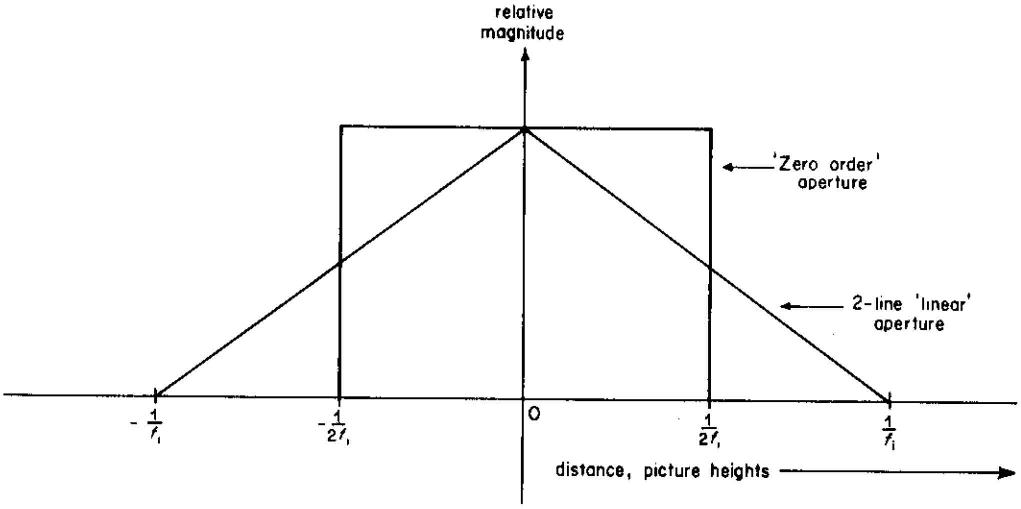


Fig. 12 - Zero-order and 2-ordinate linear apertures

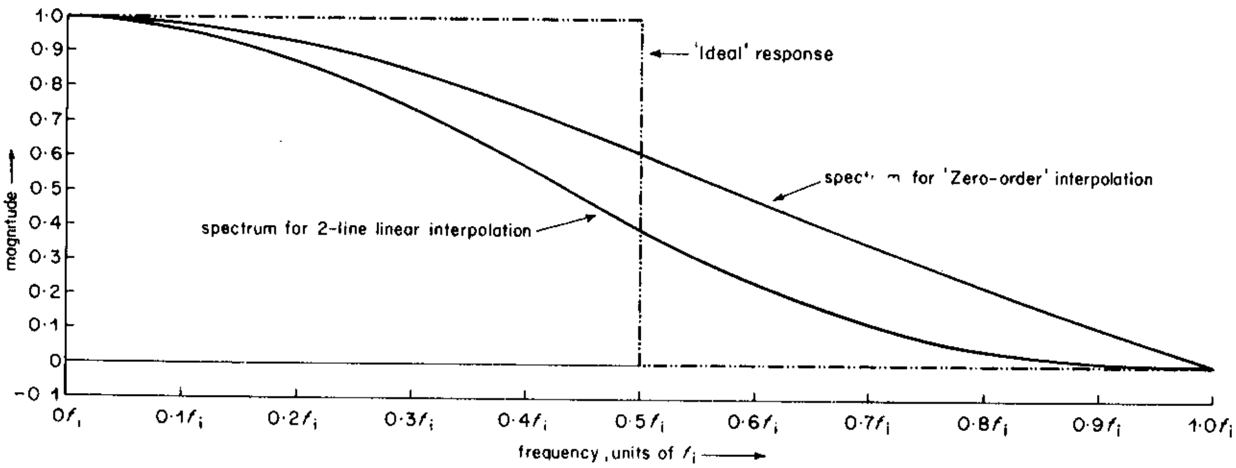


Fig. 13 - Spectra plotted for zero-order interpolation and 2-ordinate linear interpolation

Fig. 12. Using linear interpolation, each output line is derived from proportions of the signals on two successive input lines, the proportion depending on the relative position of the output line between them. This form of interpolation was included in the tests because it is easy to instrument and relatively cheap. It is also capable of acceptable performance on non-critical input material.

The spectra of zero-order and two-ordinate linear apertures are plotted in Fig. 13. The very unsatisfactory 'out-of-band' performance, particularly of zero-order interpolation is readily apparent.

6.1. The effect of varying the aperture width

6.1.1. Preliminary tests

Preliminary subjective tests were carried out by three trained observers. These observers had been working on the equipment for many weeks and were familiar with the picture impairments which could arise as a result of inadequate interpolation. The intention of this first group of tests was not to assess how subjectively important the errors were, but rather to try to obtain a relative measurement of the differences between apertures, and to compare the results with those expected from theory. Thus, subject material chosen for these tests consisted of still pictures containing horizontal and sloping edges in order to show interpolation errors more clearly. A mechanical device in the scanner was used to rock the slide vertically at a rate of about once every five seconds. This made interpolation errors more easily visible. When a picture is stationary, interpolation errors are also stationary; when the picture moves, however, the interpolation errors may appear to move in an unrelated way or may appear as an obvious stationary background against which the picture moves. Some of the slides chosen contained such critical information that they produced appreciable spurious moiré patterns even when viewed directly on 625-line television, indicating that they already contained a significant amount of information above the Nyquist sampling limit. In order to avoid confusion with genuine interpolation errors, the scanner was defocused slightly. This was, however, only done for these preliminary subjective tests.

The pictures to be compared were presented alternately on the same monitor, and the observers were asked to score the one against the other using a seven point comparison scale, thus:

+3	A IS VERY MUCH BETTER THAN B
+2	A IS MUCH BETTER THAN B
+1	A IS BETTER THAN B
0	A IS THE SAME AS B
−1	A IS WORSE THAN B
−2	A IS MUCH WORSE THAN B
−3	A IS VERY MUCH WORSE THAN B

The observers were asked to give three scores in each test, one for interpolation errors, one for their assessment of vertical resolution, and one for overall impression. The score for overall impression was intended to establish the relative importance to the observer of interpolation errors

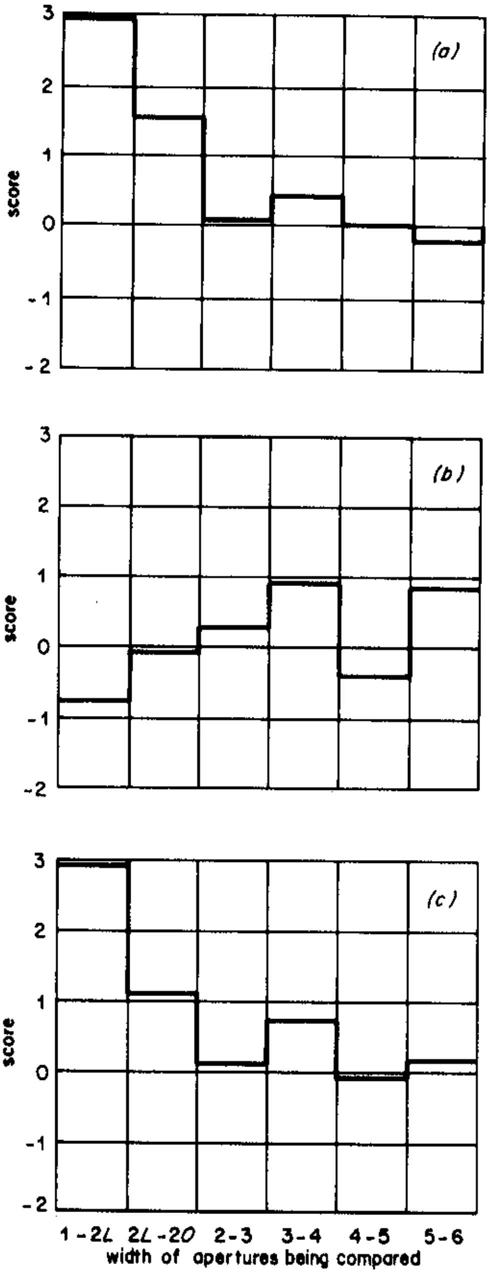


Fig. 14

(*a*) Comparative tests. Interpolation errors
(*b*) Comparative tests. Vertical definition
(*c*) Comparative tests. Overall impression

1 – 2L = Comparison between aperture of 1-ordinate and 2-ordinates (linear)
2L – 2O = Comparison between aperture of 2-ordinates (linear) and 2-ordinates (optimum)
2O – 3 = Comparison between aperture of 2-ordinates (optimum) and 3-ordinates (optimum)
3 – 4 = Comparison between aperture of 3-ordinates (optimum) and 4-ordinates (optimum)
4 – 5 = Comparison between aperture of 4-ordinates (optimum) and 5-ordinates (optimum)
5 – 6 = Comparison between aperture of 5-ordinates (optimum) and 6-ordinates (optimum)
NOTE: Positive scores indicate that last named aperture was preferable to first named.

and vertical definition. The results are summarised in Fig. 14 which shows the histogram plots obtained of average scores for the pairs of apertures being compared. As expected, in the plot of interpolation errors, there was a tendency for the improvement to diminish with the higher orders of interpolation, and the improvement in going from 3 to 4 ordinates was probably just worthwhile. The plot of vertical definition shows that zero-order was considered better than 2-ordinate linear interpolation. This is expected from the plot of the spectrum in Fig. 13, which shows that although zero-order interpolation has a worse out-of-band performance than linear interpolation, it has a better in-band performance.

The results also indicate that 4-ordinate interpolation had very slightly superior vertical resolution to 5-ordinate interpolation. In fact, they were expected to have very similar performances since the spectra of the two apertures were almost identical. The remaining results for vertical definition were much as expected. The results for overall impression matched those for interpolation very closely, and this seems to suggest that interpolation effects contribute more to the overall impression than vertical definition effects. One might conclude that, as the aperture is increased in width, an improvement is seen in the output picture up to a width of 4 ordinates, but that there is little to be gained thereafter.

6.1.2. Visibility of interpolation errors as a function of picture information

Having established with the aid of trained observers that the comparative performance between apertures agreed with theory within the limitations of the experiment, the need was seen to conduct a series of subjective tests which would yield a quantitative subjective score for the performance of each aperture. The selection of picture sources for use in subjective tests of this sort is difficult; the use of pictures obtained from slides enhances the ability of the observers to see interpolation errors because they have the opportunity to study in detail each part of the otherwise unchanging picture; this is particularly true if the slide is rocked slowly in the gate of the scanner. This series of tests was therefore intended to investigate to what extent the choice of picture information influences the visibility of interpolation errors. The EBU 6-point Subjective Impairment Scale was used, as shown below.

Grade 1	IMPERCEPTIBLE
Grade 2	JUST PERCEPTIBLE
Grade 3	DEFINITELY PERCEPTIBLE BUT NOT DISTURBING
Grade 4	SOMEWHAT OBJECTIONABLE
Grade 5	VERY OBJECTIONABLE
Grade 6	UNUSABLE

For this test and for the remaining tests, there were seven observers, who were all either engineers or technicians but who had not been involved in working on the project.

When using the impairment scale for the evaluation of interpolation errors, it is always difficult to form a clear idea of what constitutes grade 1, since even in directly scanned pictures there are often interference patterns visible which resemble these due to inadequate interpolation. It was important, therefore, to have a standard with which the scores could be compared. In order to obtain such a standard, an attempt was made to simulate the performance of the existing analogue line-store standards converters by forming an aperture with a similar spectral characteristic. It was not possible to obtain an exact match (the aperture of the analogue converters is known to be asymmetrical) but a sufficiently close approximation was obtained.*

It was decided to restrict the tests to an assessment of interpolation errors only, and the pictures used were Test Card C and three slides of subjects chosen for their demanding picture information. These slides were rocked in the gate of the slide scanner as before, so as to make the interpolation errors more easily visible. Also, an extract from the film 'Weald of Kent' was used which contains panning shots of tiled roofs and is particularly suitable for showing up interpolation errors. Each picture was shown seven times (once for each aperture) to the seven observers for approximately 20 seconds, and the results obtained are summarised in histograms in Fig. 15. The shaded regions represent the calculated standard deviations of each of the results. The absence of a shaded area indicates zero standard-deviation and hence a unanimous score by the observers. There is a trend, in all three histograms, for the score to improve as the apertures are made wider, but the improvement quickly flattens out after 4-ordinate apertures. It is interesting to note that the scores using Test Card C were very similar to those obtained using the 'Weald of Kent', whilst the scores for the slides were generally worse. The performance of the aperture simulating the analogue converter is seen to be fairly similar to apertures formed from 4 and 5 ordinates. From these tests it would seem that certain slide subjects represent very critical material which tends to score roughly two grades worse than even quite critical material from normal programmes, and that the performance of the present analogue converters is probably just as unsatisfactory under these unusually critical conditions.

6.1.3. Subjective tests using programme material

The need was seen to conduct a further series of tests using a more representative sample of programme material. Several video tape recordings were obtained and suitable passages were selected and assembled to serve as material for the tests. Careful selection was necessary before passages were obtained with material sufficiently critical to show any interpolation errors!

The observers were asked to score according to the impairment scale for interpolation errors, vertical definition,

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* The similarity was established by viewing BBC-1 (off-air) on a 405-line receiver and viewing simultaneously the output from the converter using as its input the 625-line u.h.f. BBC-1 transmissions. When using the same type of monitor to view the two pictures side by side, no difference between the pictures could be detected, even by skilled observers, and so it was concluded that this simulation of the analogue converter was realistic and fair.

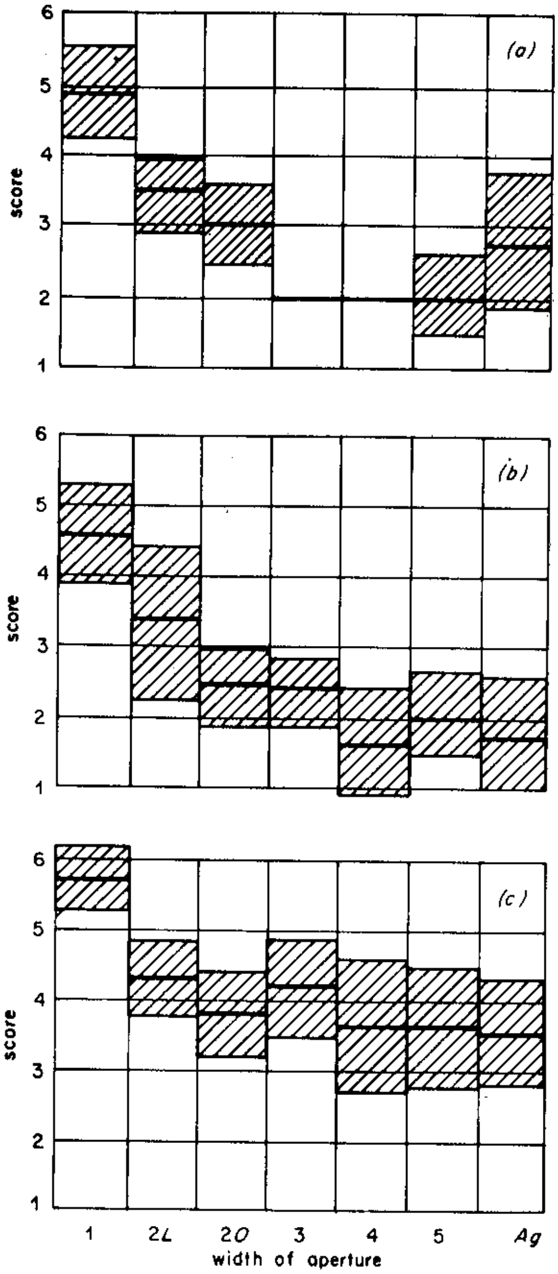

Fig. 15 - Comparison between different types of picture source

(*a*) Test Card C (*b*) Film. Extract from 'Weald of Kent'
(*c*) Mean of 3 slide subjects
1 = Zero order interpolation
2*L* = 2-ordinate (linear)
2*O* = 2-ordinate (optimised)
3 = 3-ordinate (optimised)
4 = 4-ordinate (optimised)
5 = 5-ordinate (optimised)
A.g. = Simulation of analogue line store converters

and overall impression. The results are summarised in Fig. 16. The scores for interpolation errors and overall impression were substantially the same, and both confirmed the trend already seen for the scores to flatten out for apertures formed from more than four ordinates. The histograms related to vertical definition show little variation at all; here, the score for zero-order interpolation is remarkable for its excessively high standard-deviations. This reflects confusion among the observers, and can probably be accounted for by assuming that initially they were unable to separate vertical definition impairments and interpolation impairments on a picture which contained severely distracting errors.

6.2. The effect of varying the coarseness of quantisation of the aperture function

The evidence accumulated so far from the first group of subjective tests suggests that there is no necessity to consider apertures of widths larger than 4-ordinates, since this seems consistently to be the point beyond which the sub-

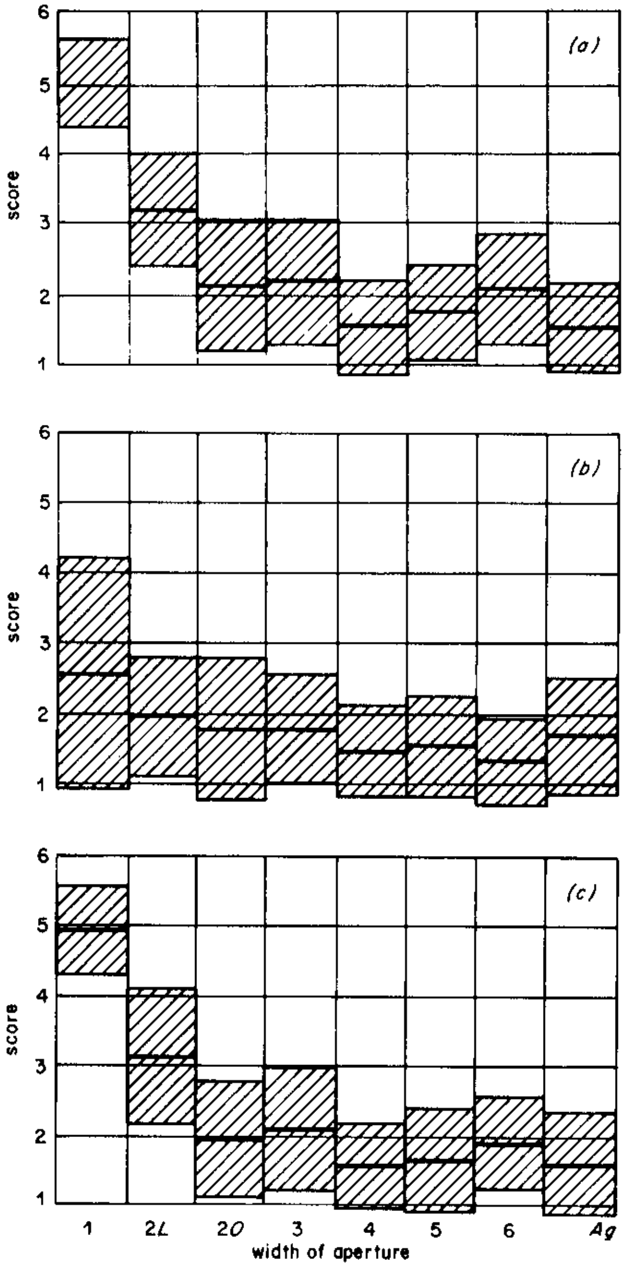

Fig. 16 - Average scores for programme material

(*a*) Interpolation errors (*b*) Vertical definition
(*c*) Overall impression
Interpretation of 1, 2*L*, 2*O*, 3, 4, 5 and A.g. as for Fig. 15

jective improvements in picture quality are minimal. It was next decided to carry out the second series of tests to determine to what extent the coarseness of magnitude quantisation of a 4-ordinate aperture could be increased before the picture was judged to be subjectively impaired. From preliminary experiments it was found that even on the most rigorous picture material the quantisation had to be brought down to 4 bits (16 levels) before any difference in performance could be seen, hence tests were carried out using 7 bits, 4 bits, 3 bits, and 2 bits, and plug-in coefficient boards were constructed accordingly.

Tests were also carried out using the 2-ordinate optimised aperture since it performed reasonably well in the previous subjective tests. Had a decision been made to economise to the maximum on the cost of future digital standards converters, the 2-ordinate optimised aperture might have been worth considering. Tests were therefore also carried out using 2-ordinate apertures with 4 bits, 3 bits and 2 bits.

During the aperture optimisation work described in Section 4, the computer program produced apertures with the property that the coefficients (being values of the aperture one-line apart) always summed to a constant value. Failure to meet this condition results in horizontal striations on the picture. Clearly, if the aperture is magnitude quantised, it does not always follow that the coefficients will sum to a constant value, even though the unquantised aperture function may do so. When deriving 7-bit apertures, the procedure used by the computer was to check the sums of the coefficients corresponding to all the permissible phases of output lines with respect to input lines and, if necessary, modify the overall gain of the aperture slightly until a fortuitous combination of coefficients giving equal sums was found. This meant that slight variations of gain between apertures were unavoidable; however they were of little importance. When quantising the apertures more coarsely, the chances of such fortuitous combinations of coefficients became progressively less, and it was sometimes necessary to adjust not only the gain but also the shape of the aperture slightly in order to make the coefficients meet this requirement. Thus the spectra of the 2-bit, and to a lesser extent, the 3-bit apertures were compromises.

The subjective tests were then carried out using the same selection of programme material as was used in the earlier tests, including Test Card C. Test Card C was included since 625-line to 405-line converters normally have to convert Test Card F during trade test periods, and Test Card C is slightly more sensitive to interpolation errors than Test Card F. The observers were asked to score impairments according to the 6-point scale for vertical definition, interpolation errors and overall impression. The results for Test Card C are summarised in Fig. 17(*a*), (*b*) and (*c*). The letters Y and B refer to the width of the aperture in ordinates and the number of bits describing it, respectively. Considering first the 4-ordinate apertures, the performance is clearly very inferior using 2 bits, but the improvement is very rapid with increasing numbers of bits, 3 bits being only just worse than 4 bits. The 2-ordinate apertures have scores which are as much as one or two grades worse than the equivalent 4-ordinate apertures, and there is a less dramatic improvement in changing from two bits to three. It would appear that from these results, four probably represents the least number of bits which should be used to define the aperture when converting Test Card, and this conclusion applies to both 2- and 4-ordinate apertures.

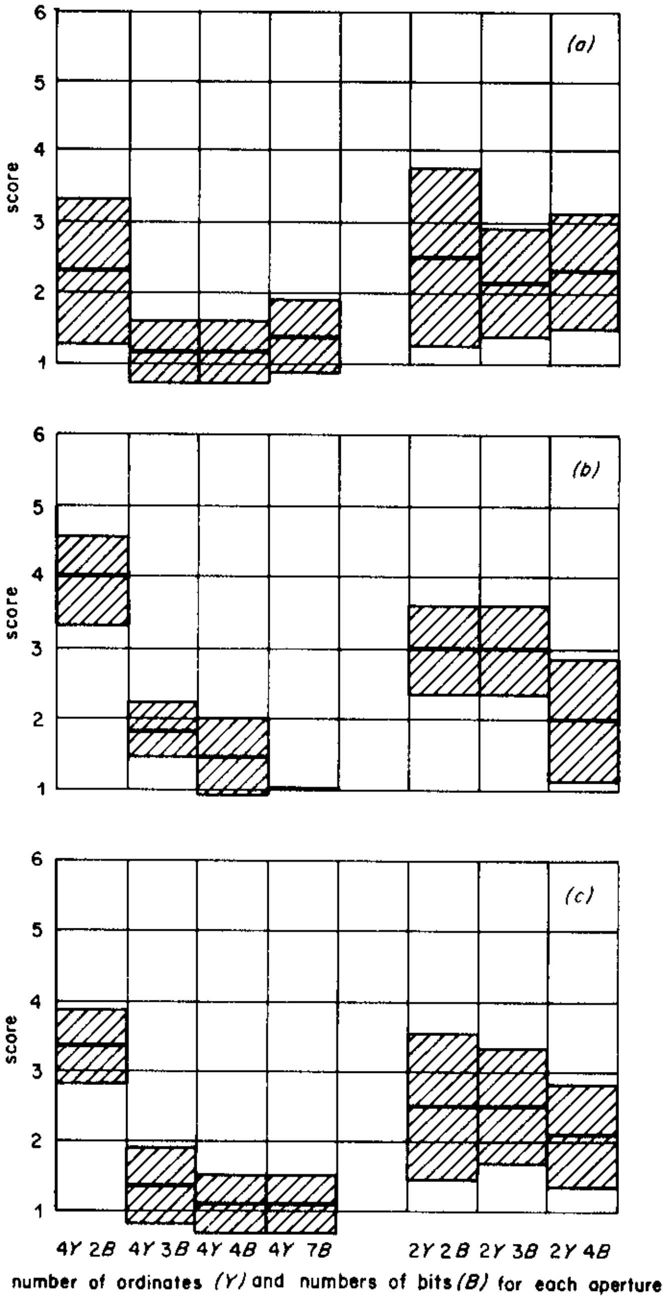

Fig. 17 - Reduction in the number of bits describing the aperture. Results for Test Card C
(*a*) Vertical definition (*b*) Interpolation errors
(*c*) Overall impression

The results of the tests using extracts from programme material are summarised in Fig. 18(*a*), (*b*) and (*c*). They reveal that the observers were far less critical than in the tests that used Test Card C and they indicate that acceptable results are obtained with all the 4-ordinate apertures and there is no preference shown for any of the 2-ordinate apertures.

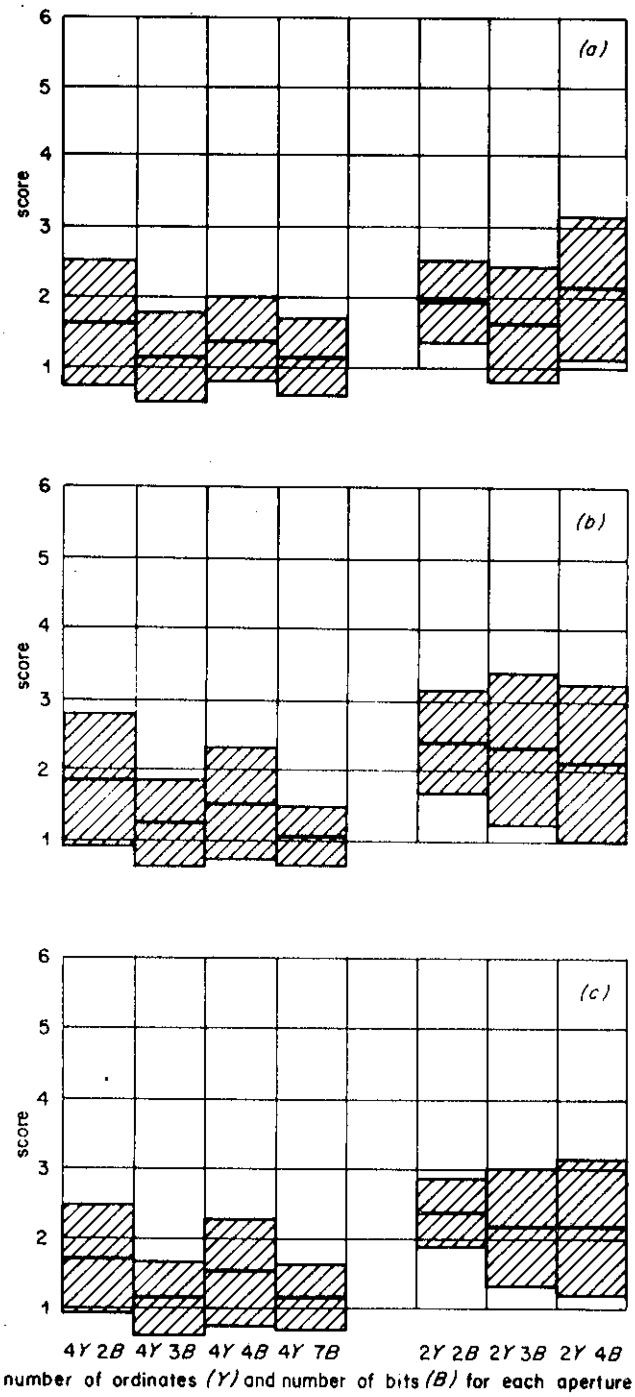

Fig. 18 - Reduction in the number of bits describing the aperture. Results for moving subjects
(*a*) Vertical definition (*b*) Interpolation errors
(*c*) Overall impression

The defects seen on Test Card when apertures quantised to two bits and, to a lesser extent, three bits, were used consisted of quasi-random disturbances down the picture. This was very obvious on an ordered scene like a test card, but could easily go unnoticed on moving programme material. This explains the lack of preference for any particular degree of level quantisation in the tests on programme material.

7. The effect of contrast law on the design of the interpolation system

The theoretical work which formed the background to this job assumed that the chosen interpolation aperture function will operate on signals that have a linear relationship to brightness. Unless special arrangements are made, however, standards converters normally receive gamma-corrected signals and some differences in performance of the interpolator can be expected under these circumstances. Section 2.9 of Research Department Report No. 1972/28 describes preliminary experiments which were carried out to determine whether gamma correction had a subjectively noticeable effect on standards converter performance using a 2-ordinate linear interpolation aperture (the only one available at that time). It was concluded then that for linear interpolation apertures there was little, if any, difference between conversion before and after gamma correction. A further series of tests using the more sophisticated apertures subsequently available confirmed these results, and no further experiments were considered necessary.

8. Conclusions and recommendations

In formulating conclusions and recommendations, it must be borne in mind that those observers chosen to take part in the subjective tests were engineers and technicians who could be expected to be very critical of the quality of the pictures shown to them. Nevertheless, interpolation errors which were often obvious to those who had been working on the equipment for some time were sometimes barely noticed by the observers. It is to be expected, then, that the general public as a whole will be even less critical. Therefore, it seems reasonable to base conclusions and recommendations on the results of these subjective tests, and to err on the side of safety. The results of the subjective tests appear to indicate that there is no advantage in using apertures formed from more than four ordinates and quantised into more than 16 levels (four bits). To the experienced eye, such an aperture was not totally without interpolation errors, but as the photograph in Fig. 19 shows, it had a very good performance

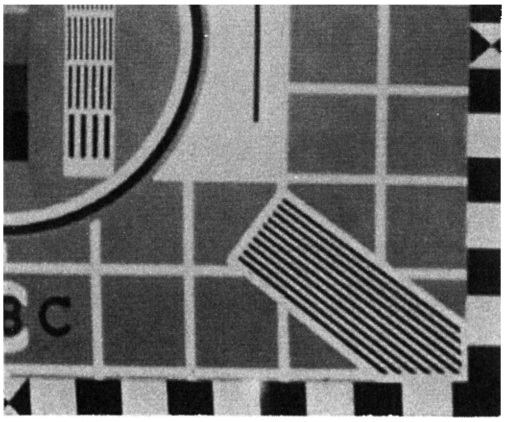

Fig. 19 - Photograph showing performance of the recommended aperture, 4 ordinates, 4 bits

which, moreover, was similar to that of the existing analogue line store converters. If there is a need for stringent economy the 2-ordinate optimised aperture, level-quantised into 16 levels (four bits) might deserve consideration since it seldom scored more than one subjective grade worse than the four ordinate aperture. Nevertheless, its inferiority is clear to the experienced observer, and it seems desirable that the standards set by the equipment currently in use should, at least, be maintained in the future.

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